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Double-tubesheet heat exchangers: Necessities and challenges

Among all types of heat exchangers, shell-and-tube heat exchangers are in huge demand for industrial applications. They are suitable for highly corrosive operating fluids and are appropriate for a broad range of pressure and temperature conditions. These heat exchangers are equipped with a single partition between the shell-side and the tube-side fluid that is popularly known as a tubesheet.

Leakage can typically occur through the tube-to-tubesheet joint, which is generally the weakest point in heat exchangers. This leakage can contaminate the other side with lower operating pressure, adversely affecting process parameters. These leakages cannot be avoided even after properly designing the tube-to-tubesheet joint by using a strength-welded and light-expanded joint with an appropriate mockup in the fabrication stage.

This article discusses double-tubesheet exchangers with a covered connected-shroud shell arrangement and presents special precautions and guidelines for manufacturers during fabrication, testing and assembly of double-tubesheet heat exchangers. It also presents two different assembly sequences that, if implemented by manufacturers, can provide a quality product.

Double-tubesheet heat exchangers are used for applications where the mixing of tube-side and shell-side fluid must be avoided. For example, chlorosilanes—either on the shell or tube side—leak through the tube-to-tubesheet joint and mix with water. They readily react with water to form corrosive hydrogen chloride (HCI) gas and hydrochloric acid, along with heat. Many chlorosilanes evolve into flammable gaseous hydrogen gas during exposure to water. Such a scenario obviously prohibits the mixing of shell-side and tube-side fluids. A comparison between a typical shell-and-tube heat exchanger and a double-tubesheet heat exchanger is presented in **FIG. 1.**

Another example of leakage is condensers in power plants. In condenser applications, water is used as a cooling medium—the cooling water (raw water) can be sea water, river water, tank or pond water. Cooling water can be brackish and full of contaminants; since the steam side is under vacuum, this water can find a way into the steam-condensed water through a tube-to-tubesheet joint. The potential for leakage of cooling water arises from tube failures, which are caused by a variety of factors. Mixing of cooling water contaminates the feed water, leading to its unacceptable chemistry.

This condensate goes to the hot well and is then pumped to the boiler with the help of a boiler feed pump. The cooling water mixing with condenser water leads to many problems on the boiler side. The affected conductivity and pH level of the boiler water can disturb boiler performance.

The primary concern is preventing contamination of treated and demineralized water due to the leakage of circulating cooling water into the condenser steam space. To overcome this possibility, the provision of double-tubesheet construction for power station condensers is mandatory in some countries.

To date, no method of joining tube-to-tubesheet exists that completely eliminates the possibility of leakage. With double-tubesheet type construction, any leaks through a tube-to-tubesheet joint will accumulate in the space between two tubesheets rather than leaking and contaminating the fluid on the other side. Therefore, while double tubesheets will not negate leakage, they will eliminate the mixing of shell-side fluid with tube-side fluid.

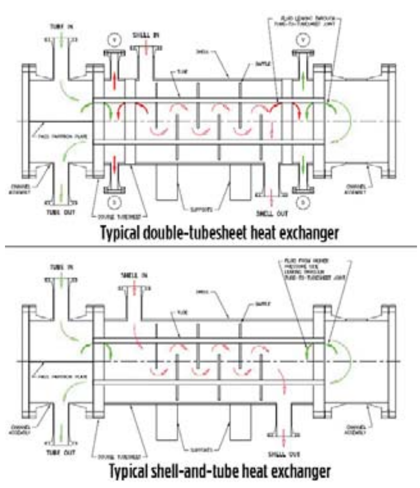

FIG. 1. A typical shell-and-tube heat exchanger vs. a typical double-tubesheet heat exchanger.

Construction. The conventional double-tubesheet exchanger has two tubesheets at both ends of the tubes. Generally, adjacent tubesheets are connected with each other by tubes. Alternatively, shroud shells can be used to cover the gap between two tubesheets. In this case, leaked fluid from either side is collected in a shroud shell.

The shell-side tubesheet of a double-tubesheet U-tube unit can be constructed with any attachment method suitable for removable bundle construction. In the case of a fixed-tubesheet arrangement, the shell-side tubesheet is welded with a shell, whereas the tube-side tubesheet may be bolted or welded with a channel. In the case of a drastic difference in mean metal temperature of the shell side and tube side and different metallurgy used for the shell-side and tube-side tubesheet, a shroud may be provided with an expansion bellow, as shown in **FIG. 2.**

Typically, the Tubular Exchangers Manufacturers Association (TEMA) covers three types of double-tubesheet

construction, shown in **FIG. 3.** In all three types of constructions, care should be taken while designing the tube-to-tubesheet joint. Primarily, the tube-to-tubesheet joint on the tube side must be strength-welded with light expansion (**FIG. 4**) to eliminate the possibility of a leakage of the tube-side fluid through the tube-to-tubesheet joint. On the other side, the tube-to-tubesheet joint on the shell side must be grooved with a minimum of two grooves and expanded to the full length, as shown in **FIG 5.** This grooved expansion joint must be selected considering the fact that on the tube-to-tubesheet joint of the shell side, welding is practically impossible.

Design. In connected (**FIG. 3B**) and integral (**FIG. 3A**) double-tubesheets, axial load distribution is accomplished by an interconnecting element/shroud shell (in the case of a connected double-tubesheet) or an integral portion of the tubesheet (in the case of integral double-tubesheet). In the integral double-tubesheet construction, an interconnecting element is so rigid that it distributes thermal and mechanical radial loads between the tubesheets and prevents the individual radial growth of tubesheets. For both constructions, tubes can mutually transfer all mechanical and thermal axial loads between the tubesheets.

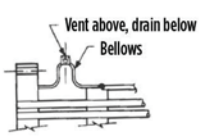

FIG. 2. With a drastic difference in mean metal temperature of the shell side and tube side and different metallurgy used for a shell-side and tube-side tubesheet, a shroud may be provided with an expansion bellow.

> Leakage can typically occur through the tube-to-tubesheet joint. Careful selection of the type of tube-to-tubesheet joint and the sequence of welding and expansion within the tubesheet are vital.

In general, various types of stresses originated in the construction include:

- Differential pressure stresses due to a difference in operating pressures between tube-side fluids and shell-side fluids
- Axial stresses due to tension or compression of the tubes; differential thermal expansion between shell and tubes is another parameter that induces axial stresses
- Shear stresses induced due to differential thermal expansion between the tubes and tubesheet in radial direction
- Thermal and pressure stresses induced due to upset conditions.

Interconnecting elements and tubes between tubesheets of the connected double-tubesheet must be designed according to these parameters:

- Interconnecting element—Radial shear stress at the junctions due to differential thermal expansion of the tubesheets
- Interconnecting element—The combined stresses due to bending and axial tension induced due to differential thermal expansion of tubesheets and thermal expansion of tubes, respectively
- Tubes—Axial tensile or compressive/buckling stresses acting due to operating pressure and thermal expansion.

Fabrication and testing. Tube-to-tubesheet leak tightness is directly affected by how the double-tubesheet exchangers are manufactured. High-quality tubesheets, baffles and tube supports are produced by drilling holes—either individually or in a stack—with the help of computerized numerically controlled (CNC) machines. The CNC machines ensure that holes in tubesheets, baffles and supports plates are concentric and precise enough to allow them to be easily occupied by tubes. If tubesheets and baffles/support plates are stacked and drilled on conventional radial drilling machines, the drill can drift as it penetrates the stack.

During assembly, hole-to-hole positions may also be displaced if tubesheet main center lines are not maintained congruently. Additionally, major difficulties may also be created if tubesheets are not kept parallel with each other. For these reasons, it is important for a purchaser to review the manufacturer's equipment/tools and techniques used for drilling and assembly.

Guidelines for manufacturers to ensure proper assembly include:

- Tube-side and shell-side faces of a tubesheet should be machined flat and perpendicular to tube (and bolt) holes. Adjacent faces of tubesheets should also be machined in similar fashion from just outside of outside tube limit (OTL) to the tubesheet periphery.
- A suitable number of spacers (made from pipe, rod or plate) should be prepared and preciously machined to the specified gap distance between the tubesheets.
- The spacers must be placed equally on the periphery between the pair of tubesheets. These aligned tubesheet pairs should be clamped and kept in place until all tubing, tube-to-tubesheet joining, and tubesheet-to-shell/channel assembly have been completed.
- A Go gauge machined from a rod that is slightly longer than the distance between the outer faces of the tubesheets should be prepared. The Go gauge ensures free entry of tubes in the tube holes of both tubesheets. Before tubing the assembly, randomly check each quadrant of the tubesheet layout to ensure that the gauge is entering freely. Since non-concentric holes

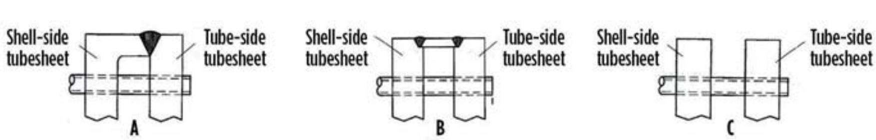

FIG. 3. Integral (A), connected (B) and separate (C) double-tubesheet type constructions.

- in adjacent double-tubesheets induce bending and shear forces on tubes and tubesheet ligaments, their concentricity is ensured with this Go gauge.
- Tubesheet ligament tolerances should be strictly ensured, as per TEMA Table RCB 7.22 or RCB 7.22M.[1] With double-tubesheet constructions, these tolerances can be made tighter based on the manufacturer's capabilities and confidence.

Careful selection of the type of tube-to-tubesheet joint and the sequence of welding and expansion within the tubesheet are vital. Displaced holes and ligament distortions make it very difficult to produce tight expanded joints. The outer tubesheet joints can be made tight by welding. However, the challenge remains at the inner tubesheet, where joints can only be made by the process of expansion, as there is no access for welding.

In general, tube end rolling (expansion) within the tubesheet should always follow the welding of the tube-to-tubesheet joint. This is due to:

- Tube expansion (rolling) before welding may leave lubricant from the tube expander in the tube holes. Other fabrication impurities can also accumulate at the tube ends. Satisfactory welds are rarely possible without extreme cleanliness.
- During tube expansion and before welding, the expander pushes tubes against the inside surface of the tubesheet in the tube holes, creating uneven gaps between the outer periphery of the tube and tube hole within the tubesheet. Successful welding with an uneven weld gap is very difficult.
- Tube-to-tubesheet joint welding after expansion creates uneven tube movement within the tubesheet due to tube thermal expansion. This leads to non-uniform tube tightness with the tubesheet surface within the tube holes, which was already achieved by rolling operation.
- Tube-to-tubesheet joint welding after expansion will trap the welding gases in the space between the outer tube surface and the tubesheet hole.

During tube expansion, the expanded portion should never extend beyond the shell-side face of the tubesheet since the removal of such a tube is extremely difficult. Additionally, tube expansion for the inner tubesheets should happen before welding to the outer tubesheets.[2]

Consequently, the correct sequences of assembly and testing are very important while fabricating the double-tubesheet construction, particularly in a fixed tubesheet—such as TEMA L, M, N and outside-packed floating heads (P-type rear heads)—where the number of tubesheets become four considering a double-tubesheet arrangement. In such cases, insertion of tubes through all four tubesheets becomes critical and presents many challenges within the facility. U-tube, double-tubesheet constructions are relatively easy in assembly.

FABRICATION AND ASSEMBLY SEQUENCES

Fabrication and assembly sequences are presented here for a fixed double-tubesheet heat exchanger.

Method 1:

- In the case of small-diameter shells, the tubesheet/baffle/tie rod/spacer skeleton should be built outside the shell, considering the inaccessible shell inside area. The same can be made inside the shell (in the case of a larger-diameter shell) where the operator can enter inside and work.
- The first bundle skeleton should be made with a tie-rod end tubesheet pair in place, as well as spacers and clamping, as discussed previously (**FIG. 6A**).
- The skeleton is then inserted into the main shell. The non-tie rod end tubesheet pair (along with spacers

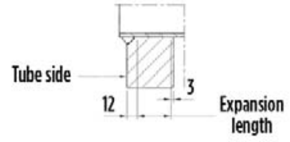

FIG. 4. A tube-to-tubesheet (tube side) joint.

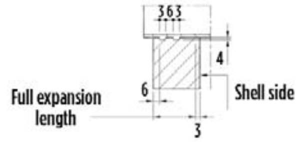

FIG. 5. A tube-to-tubesheet (shell side) joint.

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and clamping) should also be kept in line. Tack welding of the shell with shell-side tubesheets should be carried out (**FIG. 6B**).

- Tubes should be inserted from the tie rod end tubesheet pair through the skeleton and guided through the holes of the non-tie rod end tubesheet pair. Typically, a guiding rod of very small diameter (less than the tube inside diameter) is used from the opposite end (non-tie rod end) to enable tube entry through the holes in the tubesheets and baffles/support plate (**FIG. 6C**).
- Welding from the tubesheets to the main shell and non-destructive examination (NDE) are carried out (**FIG. 6C**).
- Both ends of the shell-side tube-to-tubesheet joint expansion in grooves will be carried out. The length of mandrel must be suitable for tube expansion inside the tubesheet, shown in **FIG. 6D.** Both ends of the channel-side tube-to-tubesheet joint strength welding and light expansion are completed. Tube-to-shell side tubesheet joint leak testing (with helium or air) is done based on project specific requirements. The tube-to-tubesheet joint on the shell side is tested for shell-side hydrotest pressure. Any leakage can be seen from the free space between the pair of tubesheets (**FIG. 6D**).
- Channel assembly, which has been prepared in parallel, is connected and bolted with the main shell assembly (**FIG. 6E**). The tube-to-tubesheet joint, as well as other tubeside joints, are tested for tube-side hydrotest pressure and any leaks can be detected from the free space between the pair of tubesheets (**FIG. 6E**).
- The shroud shell is rolled separately in two pieces and match fitted to ensure perfect roundness.
- After completion of all the tests, the tubesheet spacers and clamping arrangement are removed. The shroud shell is inserted in the space between the pair of tubesheets in two different parts and is then welded along the length with a root run by tungsten inert gas (TIG). The shroud shell is welded with the tubesheets (**FIG. 6F**).
- A shroud shell hydrotest is not required.

In Method 1, the shroud shell is fitted at the very end. This allows visibility through the space between the pair of tubesheets, especially during hydrotest.[3]

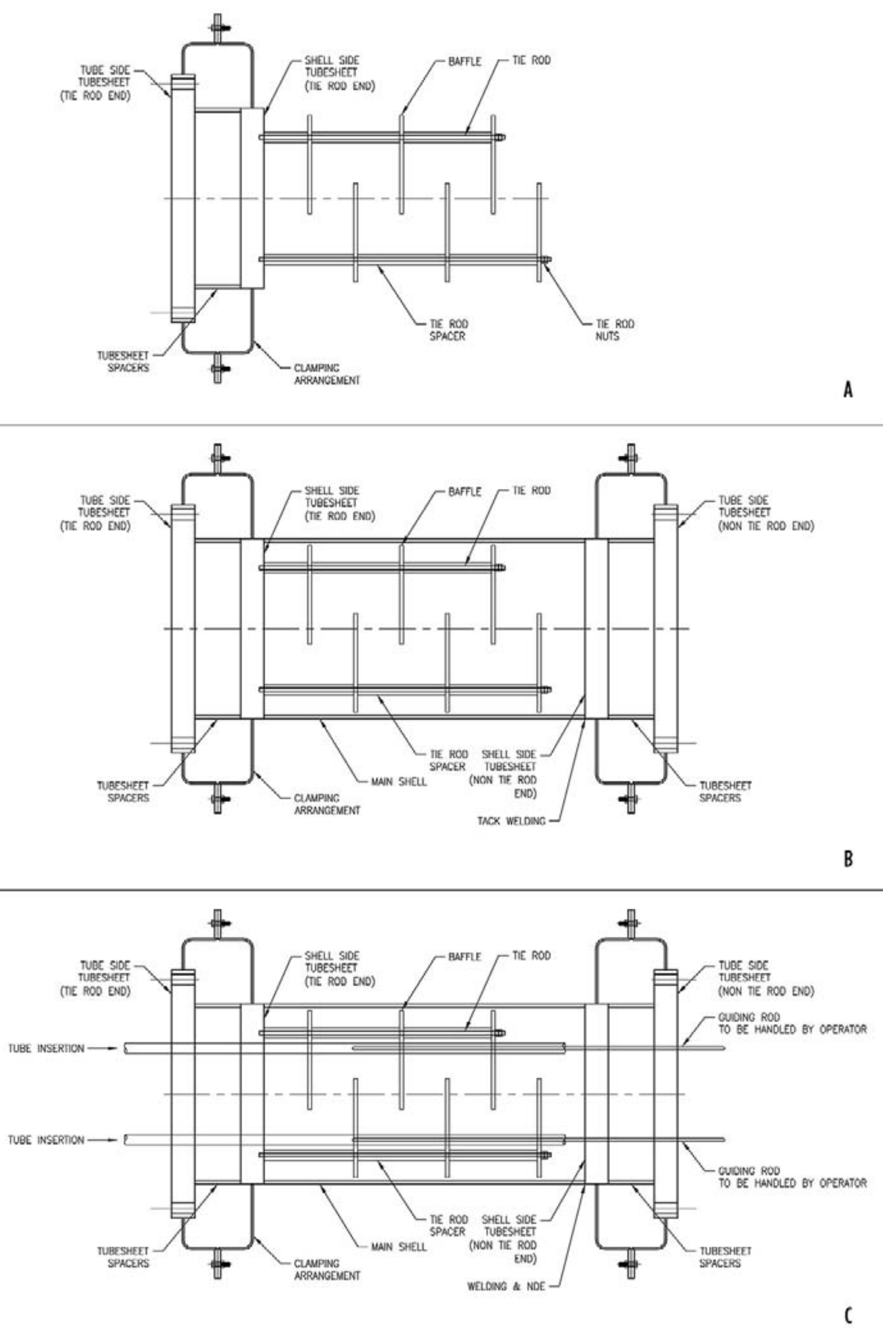

FIG. 6. (A-C) A fabrication and assembly sequence (A–F) has been presented for a fixed double-tubesheet heat exchanger.

Method 2. Method 1 may present difficulties in inserting the shroud shell in two parts—welding along the length and then with the tubesheet. To overcome this difficulty, an alternate method (Method 2) is presented here. All the steps in Method 1 should be followed except:

- The shroud shell is prepared and tack welded with one of the tubesheets on the tie-rod end side and the pair of tubesheets are prepared. In this arrangement, tubesheet clamping is still required; however, tubesheet spacers can be avoided as the shroud shell will now act as spacers. In similar fashion, the

non-tie rod end tubesheet pair is also prepared.

- The tube-to-tubesheet joint on the shell side is tested for shell-side hydrotest pressure. Any leakage must be detected with a drop in pressure because—with the presence of the shroud shell—there is no visibility in the space between the pair of tubesheets.

The manufacturer can alter the intermediate fabrication and testing sequences based on shop facilities, experience and individual technical capability.

Drawbacks of double-tubesheet heat exchangers. Although the total surface area of the exchanger is more, the effective surface area is reduced significantly because the effective tube length is measured between the inside faces of the shell-side tubesheet. The tube length surface area in the shroud area is not considered as a heat transfer area. This increases the required tube length and, in turn, the overall length of the exchanger, further increasing the cost of the heat exchanger.

The addition of two more tubesheets in double-tubesheet construction increases the cost further.

As discussed in previous sections, many criticalities and difficulties are involved in tubesheet/baffle/support plate drilling and machining, especially to achieve tube hole concentricity and tubesheet surface parallelism. Additionally, challenges exist in the correct sequence of assembly, making it difficult to produce quality product.

Maintenance of these heat exchangers can be very difficult, particularly tube removal and replacement since the tube has been fixed with tubesheets in four places. A better option is to plug the damaged tubes.

The arrangement is only possible in a fixed tubesheet, a U tube and outside-packed floating head. During the operation, the vents/drains of the shroud shell must be regularly monitored to avoid mixing of hazardous or carcinogenic fluid into the atmosphere.

Takeaway. Well-planned fabrication and assembly sequences can be useful while manufacturing double-tubesheet heat exchangers. These heat exchangers are also required in the pharmaceutical industry for sanitary applications and are designed to meet that industry's high-quality requirements and hygienic standards. These heat exchangers are also required in polysilicon manufacturing plants, as well as solar power plants. Distilled hexane reboilers, hexane heaters and titanium chloride heaters in the petrochemical industry are further examples.

This paper has presented reasons for selection of such types of heat exchangers, various types of stresses in tubes, tubesheets and shroud shell, fabrication, assembly sequences and testing methodologies. Either of the two proposed assembly sequence methods can be adopted by a manufacturer. HP

LITERATURE CITED

1. *Standards of the Tubular Exchanger Manufacturers Association (TEMA),* 9th Ed., New York, January 2007.
2. *Perry's Chemical Engineers Handbook,* 7th Ed., Mc-Graw Hill Publications, 1997.
3. *A Working Guide to Shell and Tube Heat Exchangers,* Stanley Yokell, Mc-Graw Hill, 1990.

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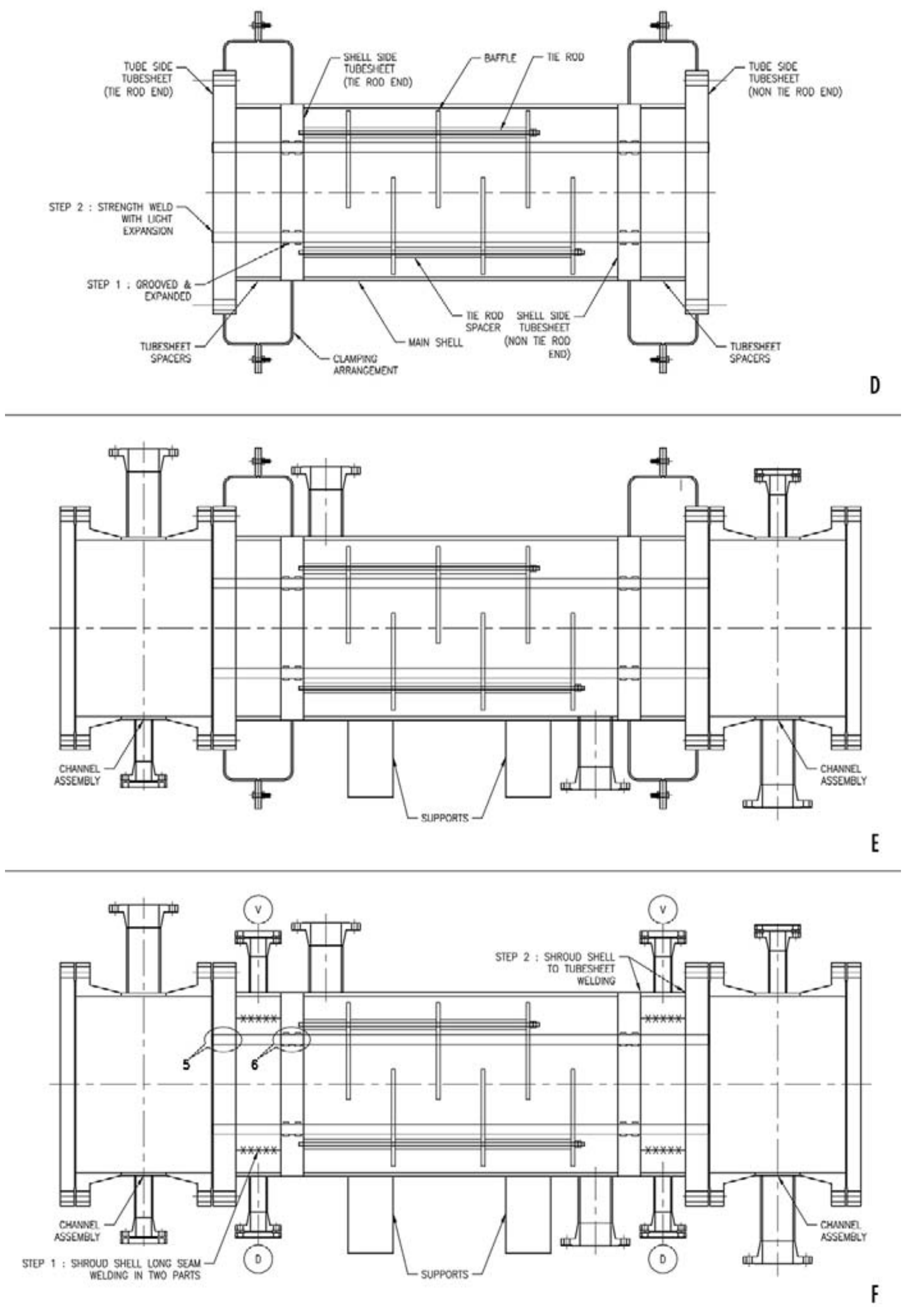

FIG. 6. (D-F) A fabrication and assembly sequence (A–F) has been presented for a fixed double-tubesheet heat exchanger.